INTRODUCTION:

Of major concern to the Industrial Hygienist is the evaluation and control of the industrial environment. One of the most important control measures for dealing with airborne contaminants is the effective use of industrial exhaust ventilation systems. To assure that the installed system is working properly and meeting requirements, routine operational inspections must be conducted. During this laboratory exercise, the student will conduct an on-site ventilation survey. The accuracy of the air flow measurements is governed by the choice of instruments. Various types of instruments for measuring flow are introduced, and the operating principles and limitations of each are emphasized.

The air flow of the ventilation system can be measured using a number of different instruments. The most commonly used instruments are the **thermoanemometer** and the **pitot tube**. A thermoanemometer can be used at the hood face and in the duct while the Pitot tube can only be used in a duct. The following is a brief description of each.

**Thermoanemometer** - contains a hot wire or heated thermocouple which relates the cooling from a moving stream of air to the velocity. This method can measure lower flow velocities than the Pitot tube and is therefore much more sensitive.

**Pitot tube** - measures VP (NOT velocity) by physically subtracting SP from TP. Pitot tubes become fairly inaccurate at less than 600 fpm. It is important to note that the tube must face the direction of air flow. See the following diagrams from the internet (or try Google Images - Pitot tube)
OBJECTIVES:

Upon completion of this laboratory, the student should:

1) Be familiar with the procedures for an on-site ventilation survey.
2) Know the principles of operation for the flow measuring devices used and the limitations of each.
3) Be able to calculate Q given velocity or velocity pressure readings.
4) Be able to estimate SP readings in a ventilation system.

EQUIPMENT:

Ventilation systems  Inclined manometer
Pitot tube  Thermoanemometer
Tape measure  Smoke tubes

PROCEDURE:

A. LABORATORY HOODS
Lab hoods generally operate either as constant flowrate (the fan is always pulling the same amount of air regardless of the sash position) or variable flowrate (the amount of air decreases as the sash is closed, to save energy).

1) Check to be sure that the hood sash (door) is opened to the recommended position (see the arrow to the left of the sash). Record the average face velocity and survey date from the lab hood’s ventilation audit sticker.

2) Measure and record the dimensions of the hood opening.

3) Visually divide the hood opening into 8 grid squares of equal area and take a velocity reading at the center of each grid square with the thermoanemometer. Be sure to hold the wand as far away from your body as possible to avoid causing flow interference from the presence of objects (bodies) in front of the hood. Be sure that you hold the wand in the plane of the hood face and that the hot wire opening is facing the direction of air flow.

4) Next, lower the sash so that there is only a one inch opening. Take 6 evenly spaced velocity readings with the thermoanemometer.

5) Now, position the sash back to the recommended position and repeat the 8 readings, but with one of your lab partners standing in front of the hood simulating someone working at the hood.

6) Repeat step 3) above with the 16-point velocity probe.

B. LOCAL EXHAUST VENTILATION SYSTEM

The ventilation system being evaluated in this lab is an actual working local exhaust ventilation system that was originally designed as a part of the Purdue Central Machine Shop system, located in the Civil Engineering Building (Room B-257). The system consists of a two-slotted welding bench and two plain end ducts, each originally positioned near a milling machine. Since this was a one-man shop, each duct from each of the three hoods has a damper so that two ducts can be shut if necessary to divert all the air flow to the hood at which the work was being performed, providing for flexibility in the system design. The room is currently being used as a materials research lab so we must be very careful as we work around their experiments to access the ventilation system (which was left in place for our use).

Become familiar with the system. By the completion of the lab period, be sure to make a sketch of the system layout, complete with all necessary dimensional details.

Important Note: For purposes of this lab, only the slotted hood and one of the plain end ducts will be operated as part of the ventilation system to be tested and measured. Check that only the slotted hood and one of the plain end duct dampers are open, and that the other plain end duct damper is closed.

Part 1. Hood Measurements

a) Slotted Hood

1) Take necessary physical measurements of the slotted hood.
2) Take 6 equally spaced velocity readings in the face of each slot to determine the average slot velocity for each slot, as well as to observe the variability of the slot velocity across the length of the slot. Also, take a reading at the center of the slot.

3) Take measurements to characterize capture velocity and the effect of distance in front of each slot, to determine the effectiveness of control during welding. Measure the velocity directly in front of and at the level of the center of each slot, at a position over the edge of the work bench and over the center of the work bench.

4) Observe the flow streamlines with a smoke tube. Take notes on your observations to correlate with your capture velocity data.

b) **Plain End Duct Hood**

1) Determine the diameter of the duct.

2) Perform two 6-point traverses (see “Important notes #1” on next page) of velocity readings across the face (opening) of the plain end duct to determine the average face velocity. Also take a reading at the center of the face.

3) Determine the capture velocity at 0.5, 1.0 and 1.5 diameters in front of the opening of the plain end duct.

4) The coefficient of entry \( C_e \) and the hood entry loss factor \( F_h \) are both measures of the efficiency of the entry of air into the hood and are related to the friction and turbulence of the entry. The \( C_e \) and \( F_h \) can be experimentally determined from the average VP and SP\(_h\) values. Locate one or more holes just downstream of the hood. Hold the tube connected to the pressure gauge firmly over each of the holes and record the SP readings in order to get an average SP\(_h\). Determine how to get the average VP from information you have collected.

5) Observe the flow streamlines with a smoke tube. Take notes on your observations to correlate with your capture velocity data.

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**Part 2. Duct Measurements**

a) **Plain End Duct Hood Measurements**

1) Locate a convenient access hole in the duct from the plain end duct hood, close to but prior to the junction of the two branches of this two-branch system. Determine the position of this point on your diagram.

2) Determine the SP at this point by holding the tubing connected to a pressure gauge firmly against the opening. This value will be used to compare to the estimated losses from the plain end duct system up to this point.

b) **System Duct Measurement After Junction**

1) Locate an access hole in the main duct at a point after the junction where the two branches leading from the individual hoods have combined and measure the SP. Take SP
readings with both the pitot tube and the tube connected to the pressure gauge. The SP value at this point will be used to compare to the estimated losses at the junction.

2) Now, at the same location as in the previous step, perform a 10-point traverse with both the pitot tube (VP measurements) and the thermoanemometer (velocity measurements). Also, take a centerline reading with each instrument in addition to the 10-point traverse.

Important Notes: 1) You will need to determine the diameter of the duct to determine the traverse positions. (See handouts)

2) When using the inclined manometer, first level it, then zero the reading. Check to see that both ends are opened to the atmosphere. The side tap (SP) should be connected to the vertical side of the manometer and the end tap (TP) to the inclined side.

3) Carefully measure the physical length of an "inch" of the vertical scale of the manometer, which reads in inches of water.

C) System Measurements Just Prior to Fan

1) Follow the duct to the fan location. Estimate the length of duct and numbers of elbows from the junction point, as well as from the point at which the duct goes through the ceiling of the shop to the test point just prior to the fan.

2) After determining the diameter of the duct, take a 10-point traverse with the thermoanemometer only, at the access point in the duct just prior to the entrance to the fan.

3) Determine the SP at this point with the probe.

RESULTS

1. For the lab hood measurements in Part A, determine the average face velocity and corresponding flowrate being exhausted by the hood for each of the measurement conditions.

2. For the ventilation system of Part B, determine the average hood slot or face velocities and corresponding flowrates being exhausted by each hood.

3. Determine the average duct velocities from the velocity traverses after the junction (both instruments’ results) and prior to the fan. Be sure to convert VP readings to velocity before calculating the average velocity for the pitot tube traverse. Compare these average velocities to the “rule of thumb” average velocity determinations using the centerline readings. Determine the estimates of flowrate at each location. How do these estimates compare to the total flowrate based on the addition of the flowrates entering the two hoods?

4. Plot the velocity contours of the duct traverses by plotting position (on x-axis) vs. velocity (on y-axis).

5. Determine the $C_e$ and $F_h$ for the plain end hood and compare to ACGIH predicted values of 0.72 and 0.93, respectively.

6. Determine the predicted capture velocities for the two hoods, using the appropriate equations (and, for the plain end duct, also use Fig. 6-6 in Industrial Ventilation, 26th ed.) for the middle and edge of the welding bench in front of each slot, and at distances from
the face of the duct opening of 0.5, 1.0 and 1.5 diameters for the plain end duct. Compare to the actual measured values.

7. Estimate the SP losses for the plain end duct hood branch, from the hood to the measurement point just prior to the junction to compare to the measured amount.

8. Estimate the SP losses for the slotted hood branch, from the hood to the junction, to compare to the measured amount.

9. Estimate the SP losses from the measurement point just after the junction to the point just prior to the fan, taking into account your estimation of the length of duct and number of elbows to compare to the measured amount of SP loss between these two points.

Note: For 7.-9., it is recommended, but not required, that you use the ACGIH Ventilation Calculation Sheets. Assume sheet metal duct for duct loss determinations.

DISCUSSION

1. How well did your average lab hood face velocity for the recommended position compare to the value certified on the lab audit sticker? How did your thermoanemometer readings compare to the multi-point readings?

2. How do your average lab hood face velocity results for the recommended and low positions compare? Comment on the amount of Q for each position. What does this tell you about the type of lab hood this is? If this had been a constant flowrate hood, what would you predict as the face velocity with the sash in the lower position, instead of what you actually measured?

3. Could the low position of the lab hood sash be classified as a slot opening? Explain how you arrived at your answer? Based on your face velocity data, could the low position of the lab hood be considered for use as an effective exterior slot hood, where it would depend on capture velocity rather than face velocity as the controlling velocity? Why or why not?

4. Comment on the variability of the velocity readings for the two sash positions. Which one was less variable and why?

5. What was the effect on the lab hood face velocity due to a person “working” at the hood? Would this compromise the safety of the worker?

6. For the machine shop ventilation system, how well did the Q generated from the hood data compare to the Q determined from the duct data (consider both duct traverses, just beyond the junction and just before the fan – if they differ, which one do you think is more accurate, and why?)

7. How did the results of the velocity traverse with the Pitot tube compare with the results of the thermoanemometer? Comment on the differences, and the pros and cons of each instrument.

8. How well did the “rule of thumb” centerline velocity predictions compare to the average velocity measurements, for the duct traverses and for the face velocity of the plain end duct? Comment on the usefulness of the rule of thumb method.
9. How do the capture velocities for each hood compare to the theoretical predicted values? For the slot hood, pay special attention to whether the measured velocities decrease as the inverse of distance or as the inverse squared of distance (i.e. which theoretical equation better predicts the experimental values: the flanged slot equation or the flanged hood equation, which is now recommended for multiple slots – see Fig. 6-11, Industrial Ventilation, 26th ed). How effective do you think these hoods would be at the actual working positions to control worker exposures?

10. Comment on the variability of the velocity across the face of the slots. Comment on the variability of the average velocity between the two slots. If it was different, why?

11. Comment on the visual observations from the smoke tubes. How well do they correlate with the measurements?

12. How do the calculated $F_h$ and $C_e$ values compare to the theoretical values for a plain end duct hood? If they differ, why do you think they do (i.e. what is different about the real hood and the theoretical hood?)

13. Comment on the shape of the duct traverse velocity contour graphs. How uniform are the velocities? Why do you suppose they are like that?

14. How did your estimate of system losses (for each hood, and for the junction to the fan) compare to the actual measurements? Why do you think there were differences?

15. Comment on any other aspect of your data as appropriate or on your experience in this lab.

CONCLUSIONS
Write six good conclusions based on your observations
**Introduction**

The objective of this lab is to measure the airflow of a ventilation system using a thermoanemometer and a Pitot tube. For week one, we conducted an eight grid square face velocity measurement of a hood in the laboratory using both a thermoanemometer and a sixteen point velocity probe. We also took these measurements with a person standing in front of the hood to see what the readings would be like if there was a worker standing there.

During week two, we went to a former welding workshop and did tests on a slotted hood, a plain end duct hood, and ducting measurements as well as on the roof of the Civil Engineering building.

**Results**

Part A. Laboratory Hoods

<table>
<thead>
<tr>
<th>Grid number</th>
<th>Measured Velocity (fpm)</th>
<th>Measured Velocity (fpm) with Worker ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>110</td>
<td>189</td>
</tr>
<tr>
<td>2</td>
<td>122</td>
<td>172</td>
</tr>
<tr>
<td>3</td>
<td>128</td>
<td>91</td>
</tr>
<tr>
<td>4</td>
<td>129</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>135</td>
<td>109</td>
</tr>
<tr>
<td>6</td>
<td>118</td>
<td>77</td>
</tr>
<tr>
<td>7</td>
<td>128</td>
<td>70</td>
</tr>
<tr>
<td>8</td>
<td>131</td>
<td>177</td>
</tr>
<tr>
<td>Avg</td>
<td>125.13</td>
<td>115.6</td>
</tr>
</tbody>
</table>

Calculated Q(cfm) ²

|                | 700.7                  | 647.4                                 |

*Area= (16 inches)(1 ft/12 inches)(50.4 inches)(1 ft/ 12 inches)= 5.6ft²

1: velocity dropped where the worker was standing but increased in the open areas

2: \( Q=AV_{avg} \)
Table 2. Determining the average face velocity of the hood opening using a 16 point velocity probe

<table>
<thead>
<tr>
<th>16 point velocity probe</th>
<th>Measured Velocity (fpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>133</td>
</tr>
<tr>
<td></td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>120</td>
</tr>
<tr>
<td><strong>avg:</strong></td>
<td><strong>125</strong></td>
</tr>
</tbody>
</table>

\[ Q = AV_{avg} \]

\[ Q = (5.6)(125) = 700 \text{ cfm} \]

Table 3. Determining the average face velocity of a 1 inch hood opening using a thermoanemometer

<table>
<thead>
<tr>
<th>Lowered sash readings</th>
<th>Measured Velocity (fpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid Number</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>900</td>
</tr>
<tr>
<td>2</td>
<td>940</td>
</tr>
<tr>
<td>3</td>
<td>920</td>
</tr>
<tr>
<td>4</td>
<td>990</td>
</tr>
<tr>
<td>5</td>
<td>930</td>
</tr>
<tr>
<td>6</td>
<td>930</td>
</tr>
<tr>
<td><strong>Avg</strong></td>
<td><strong>935</strong></td>
</tr>
</tbody>
</table>

Flowrate*: 327.25 cfm

*\[ Q = AV_{avg} \]

\[ A = (1 \text{ inch})(1\text{ ft}/12 \text{ inches})(50.4 \text{ inches})(1\text{ ft}/12 \text{ inches}) = .35\text{ft}^2 \]
Table 4. determining the average hood slot velocity exhausted by the slotted hood.

<table>
<thead>
<tr>
<th>Reading point</th>
<th>Recorded Velocity (fpm)</th>
<th>Average velocity (fpm)</th>
<th>Average top slot velocity (fpm)</th>
<th>Flowrate (cfm)**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Top Slot</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1180 1175 1190</td>
<td>1181</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1175 1090 1040</td>
<td>1102</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1020 1025 1040</td>
<td>1028</td>
<td>1148.7</td>
<td>1148.7</td>
</tr>
<tr>
<td>4</td>
<td>1150 1165 1180</td>
<td>1165</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1185 1205 1150</td>
<td>1180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1250 1240 1220</td>
<td>1236</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Center Slot</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bottom Slot</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1165 1170 1190</td>
<td>1175</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1000 980 960</td>
<td>980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1050 1045 1090</td>
<td>1061</td>
<td>1065</td>
<td>1065</td>
</tr>
<tr>
<td>4</td>
<td>1035 1030 1030</td>
<td>1031</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1025 1020 1010</td>
<td>1018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1135 1125 1115</td>
<td>1125</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Center Slot</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1080 1075 1080</td>
<td>1078</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The center slot is not included in the average velocities

** Flowrate equals Q=AV. Area = LW= 2in*(1ft/12in) *6 ft =1ft², V= average velocity of the slot.

Sample calculation of Q for top slot=> Q=AV=1*1148.7= 1148.7cfm
Table 6. Capture velocities of the slot at two distances away from the slot

<table>
<thead>
<tr>
<th>Distance</th>
<th>Capture Velocity (fpm)</th>
<th>Top Slot</th>
<th>Bottom Slot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>90</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>89</td>
<td>122</td>
</tr>
<tr>
<td>1”</td>
<td></td>
<td>89</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td>Avg: 89</td>
<td></td>
<td>Avg: 120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>61</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>59</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Avg: 59</td>
<td></td>
<td>Avg: 75</td>
</tr>
</tbody>
</table>

Table 7. Determining the average hood velocity exhausted by the plain end hood

<table>
<thead>
<tr>
<th>Distance</th>
<th>Face velocity (fpm)</th>
<th>Horizontal 6 pt traverse</th>
<th>Vertical 6 pt traverse</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>.81</td>
<td>1320</td>
<td>1150</td>
<td></td>
</tr>
<tr>
<td>1.93</td>
<td>1170</td>
<td>1295</td>
<td></td>
</tr>
<tr>
<td>Middle (3)b</td>
<td>1200</td>
<td>1160</td>
<td></td>
</tr>
<tr>
<td>4.07</td>
<td>1120</td>
<td>1190</td>
<td></td>
</tr>
<tr>
<td>5.19</td>
<td>1310</td>
<td>1305</td>
<td></td>
</tr>
<tr>
<td>5.81</td>
<td>125</td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

overall average velocityb: 1022 fpm  
Flowratec: 200 cfm

a 6 in duct diameter.  
bThe middle point is not included in the average.  
cWe calculated the flowrate by using Q=AV, where v is measured using the thermoanemometer and A is found using the formula by A= ¼πd².  
Actual reading were not taking at point 0 and 6, these values are assumptions that are not included in the average.
Figure 1. Velocity Contour of the Duct Traverse of in Plain End Hood

Table 8. Capture velocities for the Slot Hood at 2 Distances Away From the Slot

<table>
<thead>
<tr>
<th>Distance</th>
<th>Diameter</th>
<th>Capture Velocity (fpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>9</td>
</tr>
</tbody>
</table>
**Table 9. Determining the VP and Velocity in a System Duct after a Junction**

<table>
<thead>
<tr>
<th>Distance (inches)</th>
<th>VP (“wg”)</th>
<th>Velocity (fpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pitot tube</td>
<td>thermoanemometer</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>.27</td>
<td>.26</td>
<td>2042</td>
</tr>
<tr>
<td>1.08</td>
<td>.26</td>
<td>2042</td>
</tr>
<tr>
<td>2.14</td>
<td>.28</td>
<td>2119</td>
</tr>
<tr>
<td>3.04</td>
<td>.29</td>
<td>2157</td>
</tr>
<tr>
<td>5.05</td>
<td>.28</td>
<td>2119</td>
</tr>
<tr>
<td>Middle- 7 ³</td>
<td>.27</td>
<td>2081</td>
</tr>
<tr>
<td>8.95</td>
<td>.26</td>
<td>2042</td>
</tr>
<tr>
<td>10.96</td>
<td>.26</td>
<td>2042</td>
</tr>
<tr>
<td>11.9</td>
<td>.25</td>
<td>2003</td>
</tr>
<tr>
<td>12.9 ³</td>
<td>--</td>
<td>2020</td>
</tr>
<tr>
<td>13.7 ³</td>
<td>--</td>
<td>1840</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>average ³ (fpm)</td>
<td></td>
<td>2071</td>
</tr>
<tr>
<td>flowrate ³ (cfm)</td>
<td></td>
<td>2214</td>
</tr>
</tbody>
</table>

a. Measured with pitot tube  
b. Center point of duct, average not included  
c. The pitot tube could not reach all the way into the duct, so we don’t have values for these distances  
d. Does not contain data collected at the center point  
e. Calculated using the formula \( Q = AV \), where \( V \) is measured using a thermoanemometer and \( A \) is found with the formula \( A = \frac{1}{4\pi d^2} \), with \( d = 14 \text{inches} \times (1 \text{ft}/12 \text{in}) \), \( A = 1.069 \)  
f. \( V \) is calculated by the equation \( V = 4005 \sqrt{VP} \)

**Table 10. Determining the Velocity in a system duct prior to the fan**

<table>
<thead>
<tr>
<th>Distance (inches)</th>
<th>Velocity (fpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thermoanemometer</td>
</tr>
<tr>
<td>1</td>
<td>1560</td>
</tr>
<tr>
<td>2</td>
<td>1190</td>
</tr>
<tr>
<td>3</td>
<td>1610</td>
</tr>
<tr>
<td>4</td>
<td>1300</td>
</tr>
<tr>
<td>5</td>
<td>1280</td>
</tr>
<tr>
<td>Middle- 6 ³</td>
<td>1270</td>
</tr>
<tr>
<td>7</td>
<td>1580</td>
</tr>
<tr>
<td>8</td>
<td>1980</td>
</tr>
<tr>
<td>9</td>
<td>2250</td>
</tr>
<tr>
<td>10</td>
<td>2620</td>
</tr>
<tr>
<td>Average (fpm)</td>
<td>1664</td>
</tr>
<tr>
<td>Flowrate ³ (cfm)</td>
<td>1779</td>
</tr>
</tbody>
</table>

a. Center point was not included in the calculation of the average velocity  
b. Calculated using the formula \( Q = AV \), where \( V \) is measured using thermoanemometer and \( A \) is found with the formula \( A = \frac{1}{4\pi d^2} \), with \( d = 14 \text{inches} \times (1 \text{ft}/12 \text{in}) \), \( A = 1.069 \)
**Cₚ for plain end hood**

\[ C_p = \sqrt{\frac{VP}{SP_h}} \], where \( SP_h \) was found to be 0.12” wg and \( VP \) is determined using the average velocity* and the formula:  \( VP = \left(\frac{V}{4005}\right)^2 \)

\[ VP = \left(\frac{1022}{4005}\right)^2 = 0.065” \text{ wg} \]

\( C_p = \sqrt{\frac{0.065}{0.12}} = 0.74 \)

The actual value of \( C_p \) is 0.72

Percent error: \( \frac{|0.72 - 0.74|}{0.72} = 2.8\% \)

*Average velocity was found by taking the overall average velocity of the horizontal and vertical 6-pt traverses.
**F<sub>h</sub> for the plain end hood**

\[
F_h = \frac{SP_h}{VP} - 1
\]

\[
F_h = \frac{12}{0.065} - 1 = 0.85
\]

The actual value of \(F_h\) is .93

Percent error: \[
\frac{|0.93 - 0.85|}{0.93} = 8.6%\]

**Capture Velocities for the Two Hoods**

- **PLAIN END HOOD (6” diameter)**

*For 0.5 diameters away*

\[
V_c = \frac{V}{10x^2 + A}, \text{ Where } Q \text{ is the average flow rate, } x \text{ is the distance from the face the measurements are taken, and } A = \pi r^2 = \pi (.25)^2 = .196 \text{ ft}^2
\]

\[
V_c = \frac{200 \text{ cfm}}{10(.25)^2 + .196} = 243.61 \text{ fpm}
\]

The actual measured value was 185 fpm.

Percent error: \[
\frac{185 - 243.61}{185} = .3168 * 100 = 31.68%\]

*For 1.0 diameters away*

\[
V_c = \frac{200 \text{ cfm}}{10(.5)^2 + .196} = 74.18 \text{ fpm}
\]

The actual measured value was 70 fpm.

Percent error: \[
\frac{70 - 74.18}{70} = .0597 * 100 = 5.97%\]

*For 1.5 diameters away*

\[
V_c = \frac{200 \text{ cfm}}{10(.75)^2 + .196} = 34.36 \text{ fpm}
\]

The actual measured value was 40 fpm.

Percent error: \[
\frac{40 - 34.36}{40} = .141 * 100 = 14.1%\]
### Slotted Hood

- **Top Slot and Bottom Slot face velocities at 1 and 2 feet away**

Since the ratio is .19 we did calculations for the slots and as a plain end hood in order to compare to see which one is better at calculating the face velocity.

<table>
<thead>
<tr>
<th>Feet away and corresponding slot</th>
<th>Actual Measured face velocity</th>
<th>Equation 1 (fpm)*</th>
<th>Equation 2 (fpm)**</th>
<th>Percent Error (%)***</th>
</tr>
</thead>
<tbody>
<tr>
<td>1’ top slot</td>
<td>89 fpm</td>
<td>139.3</td>
<td>73.63</td>
<td>56.52</td>
</tr>
<tr>
<td>2’ top slot</td>
<td>59 fpm</td>
<td>37.36</td>
<td>36.82</td>
<td>36.68</td>
</tr>
<tr>
<td>1’ bottom slot</td>
<td>120 fpm</td>
<td>129.09</td>
<td>68.27</td>
<td>7.04</td>
</tr>
<tr>
<td>2’ bottom slot</td>
<td>78.33 fpm</td>
<td>34.63</td>
<td>34.13</td>
<td>55.79</td>
</tr>
</tbody>
</table>

* (1) \(V = \frac{Q}{0.75(10x^2 + A)}\) where \(Q\) equals the flow rate of the corresponding slot (top: 1148.7 or bottom: 1065), \(X= 1’\) or 2’ (depending on which one we are solving for, and \(A\) equals the area which is \(L*W = 2\text{in} \times (1\text{ft}/12\text{in}) \times 6\text{ft} = 1 \text{ft}^2\)

** (2) \(V = \frac{Q}{2.6 LX}\) where \(Q\) equals the flow rate of the corresponding slot (top: 1148.7 or bottom: 1065) and \(L= 6’\) and \(X= 1’\) or 2’ (depends on which one we are solving for)

*** Percent Error = \(|\text{experimental value} - \text{actual value}| / \text{actual value} \times 100\)

### Sample Calculation:

1 **feet away**

Calculation as plain end

\[V = \frac{Q}{0.75(10x^2 + A)}\]

\[V = \frac{1148.7}{0.75(10(1)^2 + 1)} = 139.3 \text{ fpm}\]

Calculation as a slot

\[V = \frac{Q}{2.6 LX}\]

\[V = \frac{1148.7}{2.6 (6*1)} = 73.63 \text{ fpm}\]

The actual measured face velocity was 89 fpm. This yields a percent error of:

Percent Error for equation 1: \(|139.3 - 89| / 89 = .5652*100 = 56.52\%\)

Percent Error for equation 2: \(|73.63 - 89| / 89 = .1727*100 = 17.26\%\)
DISCUSSION

1.) The average lab hood velocity for the recommended position was 125.13 fpm for the thermoanemometer while the value certified on the audit sticker stated that the hood velocity should be 130 fpm. Therefore the thermoanemometer measured a face velocity of 4.87 fpm lower than the audit sticker indicated. The 16 point velocity probe measured 125 fpm which is 5 fpm lower than the audit sticker measurement at the recommended hood position. Our thermoanemometer and our 16 point readings were the same.

2.) The average lab hood face velocity for the recommended position was 125.13 fpm while the average face velocity for the lower sash position was 935 fpm. The recommended position was 87% lower than the lower sash position. The flowrates for the recommended position and the lower sash position were 700.7 and 327.25 respectively. This tells us that the hood in Sam’s office is a variable volume hood. We predict that with the constant flowrate hood, the low position flowrate and the recommended position flowrate should be the same.

3.) The hood can be considered as a slot opening when the sash is in the low position due the ratio being less than 0.2. In the lab our aspect ratio equals 1/ 50.4 or 0.02. Based on our measurements taken in lab, we determined the distance from the slot in which a contaminant can be captured. This was calculated using the equation Q= 3.7LXV. Our V, Q, and L were 935 fpm, 327.25 cfm, and 50.4in (4ft) respectively. After plugging the values in to the equation for a plain end slot and solving for x, we determined that the hood with the lower position (1” opening) can effectively capture a contaminant .024 ft away.

4.) The low position velocity readings were less variable than the recommended position velocity readings. This due to the smaller area the air is required to flow through.

5.) The average face velocity with the worker in position was 647.4 fpm with is 8% lower than the average face velocity without the worker which was 700.7. This would compromise the safety of the worker because the potential contaminants the worker is using may not be fully removed by the hood due the lower velocity. The lower velocity could also lead to settling.

6.) Q generated from the hood differs from the Q generated from the duct. The Q generated from hood equals 2213.7 cfm, the q generated from the plain end duct equaled 200 cfm, the Q generated from the duct traverse after the junction equaled 2168 cfm, and the Q generated from the duct traverses prior to the fan equaled 1779 cfm. The flowrates for the duct traverse after the junction were measured by two different devices so the values were averaged in order for them to be compared. The flowrate prior to the fan was less accurate due to the fact that it was taken just after the 90 degree elbow.

7.) The results of the velocity traverse for the Pitot tube and the one for the thermoanemometer are similar. At 2.14 inches the Pitot tube read 2119 fpm and thermoanemometer was 2120 fpm. The pitot tube is a primary standard for velocities. It is a tube within a tube that measures SP and TP. However it is not the best instrument for low velocities. The thermoanemometer is a delicate device that has a wide range of applicability (10 – 8000 fpm). However it is not the best instrument for dusty or combustible environments.
8.) The rule of thumb rule estimates the average velocity using the centerline velocity measurement. With the equation .09*V_{cl} = V_{avg}. The centerline velocity for the plain end duct was measured to be 1200fpm for the horizontal traverse and 1160 fpm for the vertical traverse. When plugged into the rule of thumb equation we were able to find the V_{avg} of 1080 fpm for the horizontal and 1044 fpm for the vertical traverse. These values were similar to what we calculated to be the V_{avg}. The values we calculated were 1009 for the horizontal traverse and 1034 for the vertical traverse. This is a 7% (horizontal) and .96% (vertical) percent difference. For the duct traverse before the junction was 2081 fpm. The V_{avg} that was calculated with the rule of thumb approach was 1872 and the V_{avg} we calculated was 2071 fpm. In this case the rule of thumb underestimated the V_{avg} by almost 200 fpm. The centerline velocity for the traverse prior to the fan was 1270. When the rule of thumb calculation was done to determine the V_{avg} we found the result to be 1143. The average velocity we calculated was 1664 fpm. This is a 31% difference.

9.) The calculated values for the capture velocities for the plain end duct were 243.6 for the .5 diameters away, 74.18fpm for 1 diameter away, and 34.36fpm for 1.5 diameters away. When compared to the actual values of 185, 70, and 40 respectively the values were close. The .5 diameter values had a 31.68% difference. The 1 diameter values had a 5.97% difference. Finally the 1.5 diameter values had a 14.1% difference. The values for the slotted hood show more variance. The capture velocities for the slots were calculated in two ways. The first way was by using the equation for a plain end hood (equation 1) and the second was by using the equation for a slot (equation 2). The two methods gave us different percent errors. For the top slot at 1 ft away we received a 56.52% difference using equation 1 and a 17.26% difference using equation 2. The top slot two feet away yielded a percent difference of 36.68% and 37.835 using equations 1 and 2 respectively. The percent errors for the bottom slot showed 7.04% difference (equ.1) and 43.11% difference (equ.2) at 1ft away and 55.79% (equ 1) and 56.43% (equ.2 ) at 2ft away. The hoods would be effective in actual working positions because the velocities are lower than the actual which tells us that the hoods are running at a safe speed for the worker.

10.)The top slot had an overall higher face velocity than the bottom slot. The top slots face velocity was 1148.7fpm and the bottom slots velocity was 1065 fpm. The top slot had a higher velocity and flow rate due to the fact that the slot was closer to the fan than the bottom slot.

11.)The visual observation of the smoke tubes showed that the slotted hood and the plain end hood were both functioning to pull in air. The smoke correlated with our measurements. The top slot pulled the smoke in quicker than the bottom slot. The smoke was also pulled in slower as the smoke tube got further away from the slots.

12.)The F_h and the C_e values were calculated for the plain end duct and then compared to the theoretical values. The theoretical values were .72 for F_h and .93 for C_e. The calculated F_h was .85 which yields a 8.6% difference when compared to the theoretical. The calculated C_e was .74 which yields a 2.8% difference when compared to the theoretical. The real hood and the theoretical hood could have a different VP or SP value. The real hood could have had a higher VP or a lower SP than the theoretical hood.
13.) The duct traverse velocity contour graph for the plain end hood shows a difference between the horizontal and the vertical traverses. However the overall shape of the two graphs for both the traverses are similar. Both traverses show an increase in velocity the closer we got to the edge of the duct but the center of the traverses were steady. The horizontal traverse was also lower in comparison to the vertical traverse.

The duct traverse velocity graph contour for the data, before the junction and prior to the fan, has two completely different shapes. The velocity traverse for after the junction showed consistent values. The velocity traverse prior to the fan had consistent values for the first five points then started to rise linearly for the next five points.

14.) The calculated system losses were close to the actual system losses. The SP losses from the plain end hood to just before the junction had a 10.19% difference. The SP losses for the slotted hood branch to the junction had a 5.44% difference. The SP losses from the measurement point to just after the junction to the point just prior to the fan had a 20.22%

15.) This lab was great experience. It allowed us to have hands on activities that helped us better understand what we were learning in class.

Conclusions

1.) We conclude that the face velocity of a hood decreases when a worker is working in front of the lab. This is based on the lab hood readings taken from the first week of lab.

2.) We conclude that the smaller the hood area the less variable the velocity readings are.

3.) Based on the centerline velocities and the average velocity measurements taken during week two, we conclude that the “rule of thumb” method for estimating the average velocity is accurate for the duct traverse but not for the plain end duct.

4.) Based on the velocities taken during the first week of lab, we conclude that the low position of the sash had a higher velocity than that of the recommended position due to it having a smaller area.

5.) Based on the calculations for the capture velocity of the slotted hood using the plain end hood equation and the equation for the slot, we conclude that the equation for the slot was better at calculating the capture velocity of the hood than the equation for the plain end hood.

6.) Based on the velocity contour graph for the duct traverse prior to the fan, we concluded that since the traverse velocities (measured just after an elbow) are higher on one side of the traverse than they are on the other side, the rule of thumb method should not be used to estimate the average velocity.